

MEMORANDUM REPORT

Friant Dam Spillway Rehabilitation
Hydraulic Model Study

by

James A. Higgs

Water Resources Research Laboratory
Bureau of Reclamation



for

Mid-Pacific Region
United States Bureau of Reclamation

May 1996

Friant Dam Spillway Rehabilitation
Hydraulic Model Study

By James A. Higgs

Water Resources Research Laboratory
Water Resources Services
Denver Technical Center
Denver, Colorado

May 1996

Acknowledgments

Thanks to Bruce Muller and Bill Fiedler from Reclamation's Technical Service Center for providing technical information. A special thanks to Cliff Pugh for invaluable input and guidance.

The information contained in this report regarding commercial products or firms may not be used for advertising or promotional purposes and it is not to be construed as an endorsement of any product or firm by the Bureau of Reclamation.

CONTENTS

Page

INTRODUCTION	1
BACKGROUND	1
PURPOSE OF STUDY	5
CONCLUSIONS	5
HYDRAULIC MODELING PREPARATION	5
MODEL CONSTRUCTION	5
OPERATIONAL CONSIDERATIONS	6
SIMILITUDE	6
TAILWATER STAGE-DISCHARGE RELATIONSHIP	9
INVESTIGATION	10
OPTIMUM CREST SHAPE	10
RUBBER GATE FABRIC EVALUATION AND GATE CONSTRUCTION	14
<i>Sumigate rubber gate model #1</i>	14
<i>Sumigate model #2</i>	16
<i>Bridgestone model</i>	16
RUBBER GATE PERFORMANCE	16
<i>Sumigate rubber gate model #1</i>	17
<i>Sumigate model #2</i>	17
<i>Bridgestone model</i>	18
GATE POSITIONING CRITERIA	20
RECOMMENDATIONS	21

TABLES

TABLE 1. MODULUS OF ELASTICITY AT 5 PERCENT ELONGATION AND SPECIFIC GRAVITY	15
TABLE 2. FABRIC RESISTANCE TO BENDING.	15
TABLE 3 MODEL FABRIC SELECTION MATRIX	15

FIGURES

FIGURE 1. FRIANT DAM.	1
FIGURE 2. FRIANT DAM IS ON THE SAN JOAQUIN RIVER AND 20 MILES NORTH OF FRESNO, CALIFORNIA.....	2
FIGURE 3. FRIANT DAM -- PLAN AND LAYOUT.....	3
FIGURE 4. FRIANT DAM SPILLWAY.	4
FIGURE 5. PREFERRED OPTION FOR THE SPILLWAY REHABILITATION.....	4
FIGURE 6. THE FRIANT DAM MODEL.	6
FIGURE 7. TAILWATER RATING CURVE FOR THE SAN JOAQUIN RIVER DOWNSTREAM OF FRIANT DAM.....	9
FIGURE 8. DETAILS OF THE 7' 1-1/2" BULL NOSE.	10
FIGURE 9. DETAILS OF THE 10' 6" BULL NOSE.	10
FIGURE 10. DETAILS OF THE ELLIPTICAL CONFIGURATION.....	10
FIGURE 11. STAGE-DISCHARGE FOR THE MODELED APPROACH CONFIGURATIONS.....	11
FIGURE 12. PRESSURES FOR THE 7 FT 1-1/2IN CONFIGURATION, MEASURED AT THE LEFT SIDE OF THE SPILLWAY BAY.....	11
FIGURE 13. PRESSURES FOR THE 7 FT 1-1/2IN CONFIGURATION, MEASURED AT THE CENTER OF THE SPILLWAY BAY.....	12
FIGURE 14. PRESSURES FOR THE 10 FT 6 IN CONFIGURATION, MEASURED AT THE LEFT SIDE OF THE SPILLWAY BAY.....	12
FIGURE 15. PRESSURES FOR THE 10 FT 6 IN CONFIGURATION, MEASURED AT THE CENTER OF THE SPILLWAY BAY.....	13
FIGURE 16. PRESSURES FOR THE ELLIPTICAL CONFIGURATION, MEASURED AT THE LEFT SIDE OF THE SPILLWAY BAY.....	13
FIGURE 17. PRESSURES FOR THE ELLIPTICAL CONFIGURATION, MEASURED AT THE CENTER OF THE SPILLWAY BAY.....	14
FIGURE 18. SUMIGATE MODEL #2. THE PIER EXTENSIONS WERE ADDED AFTER THIS PHOTOGRAPH WAS TAKEN.	16
FIGURE 19. BRIDGESTONE MODEL.	16
FIGURE 20. SUMIGATE MODEL GATE #2.....	17
FIGURE 21. SUMIGATE MODEL #2 STAGE-DISCHARGE COEFFICIENTS FOR VARIOUS GATE HEIGHTS	19
FIGURE 22. BRIDGESTONE MODEL GATE.....	20
FIGURE 23. STAGE-DISCHARGE CURVE FOR THE BRIDGESTONE GATE.....	20
FIGURE 24. SINGLE BAY DISCHARGE USING SPECIFIC DRUM GATE HEIGHTS.....	21
FIGURE 25. RECOMMENDED SPILLWAY GATE POSITIONING CRITERIA FOR USING BRIDGESTONE GATES IN THE OUTSIDE BAYS.	22

GLOSSARY

E	.....	Modulus of elasticity
E_m	.....	Model modulus of elasticity
E_p	.....	Prototype modulus of elasticity
F	.....	Froude number
F_m	.....	Model Froude number
F_p	.....	Prototype Froude number
g	.....	Acceleration of gravity
I	.....	Moment of inertia
I_m	.....	Model moment of inertia
I_p	.....	Prototype moment of inertia
L_r	.....	Characteristic length
L_m	.....	Model Characteristic length
L_p	.....	Prototype Characteristic length
Q	.....	Discharge
Q_m	.....	Model discharge
Q_p	.....	Prototype discharge
S	.....	Structural Merit number
S_m	.....	Model Structural Merit number
S_p	.....	Prototype Structural Merit number
T	.....	Time
T_m	.....	Model Thickness
T_p	.....	Prototype Thickness
t	.....	Thickness
t_m	.....	Model thickness
t_p	.....	Prototype thickness
V	.....	Velocity

V_m	Model velocity
V_p	Prototype velocity
w	Loading
w_m	Model loading
w_p	Prototype loading
γ	Unit weight
γ_m	Model unit weight
γ_p	Prototype unit weight

INTRODUCTION

Background

Friant Dam (Figure 1), a concrete gravity structure, is on the San Joaquin River approximately 20 miles north of Fresno, California (Figure 2). The dam was completed in 1942 with closure occurring in February 1944. The crest of the dam, at elevation 585 ft, is 3,488 ft long and 20 ft wide. The maximum base width is 267 ft (Figure 3).



Figure 1. Friant Dam. Millerton Lake Reservoir can be seen at the top of the picture. The San Joaquin River can be seen at the bottom. The Madera and Friant-Kern Canals can be seen on the left and right respectively.

The spillway consists of an ogee-shaped overflow section, chute, and a stilling basin at the center of the dam, and is controlled by three 100 ft wide by 18 ft high drum gates (Figure 3). The ogee crest elevation is at 560 ft. The top of the fully raised drum gates is at elevation 578 ft. The capacity of the spillway at the top of joint use, elevation 578 ft, is 83,020 ft³/s.

At the top of joint use pool, elevation 578 ft, Millerton Lake Reservoir has a capacity of 520,528 acre-feet. The San Joaquin river immediately below the reservoir has a “within-the-bank” capacity of 15,000 ft³/s. Due to flood control regulations and agreements, downstream releases from Friant Dam are restricted to quantities that will not cause downstream flows to exceed, whenever possible, any of the following criteria:

- A. 8,000 ft³/s between Friant and Skaggs Bridge at U. S. Geological Survey (USGS) gauging station “San Joaquin River below Friant,” and at USGS Service Station “Little Dry Creek near Friant,” and into “Little Dry Creek from Big Dry Creek Reservoir.”
- B. 10,000 ft³/s at USGS gauging station San Joaquin River near Mendota.

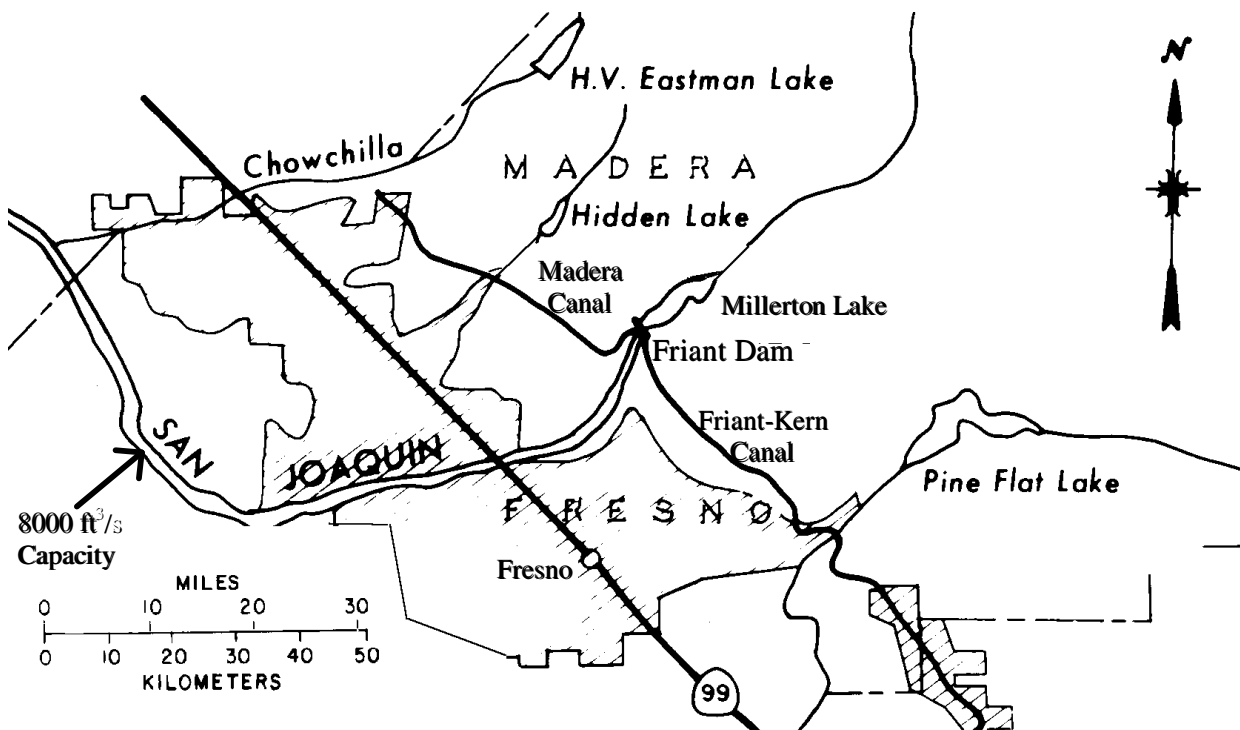


Figure 2. Friant Dam is on the San Joaquin River and 20 miles north of Fresno, California

Releases in excess of the above restrictions will impact primarily on farmland in the San Joaquin River valley. The inundation map indicated that several small communities would be affected by the worst case scenario and there would be a definite hazard to human life.

There are three separate outlet-works at the dam: the river outlet works, the Friant-Kern Canal, and the Madera Canal. The river outlet-works consists of four 110-inch-diameter steel pipes through the dam controlled by four 96-inch-diameter hollow-jet valves at the outlet ends, and a corresponding chute and stilling basin. Hydraulic turbines have been placed on two of the river outlets. The total design capacity of the four hollow-jet valves is 16,400 ft³/s when water surface of Lake Millerton is at elevation 578 ft. Small releases to the river are made through two 24-inch-diameter steel pipes which branch from penstocks 3 and 4 and are controlled by two 18-inch-diameter needle valves at the outlet ends.

The Friant-Kern Canal outlet works consist of four 110-inch-diameter steel pipes through the dam controlled by two 96-inch-diameter hollow-jet valves and two hooded fixed cone valves that bypass the power plant. The canal capacity at the head is 5,300 ft³/s.

The Madera Canal outlet works consist of two 91-inch-diameter steel pipes through the dam; controlled by two 86-inch-diameter interior differential needle valves at the outlet ends, and a stilling basin. The canal capacity at the head is 1,275 ft³/s.

Due to alkali-aggregate reaction at Friant Dam, the outside spillway drum gates may become inoperable in the next 2 to 4 years. The alkali-aggregate reaction is causing the concrete to expand, which is creating movement of blocks 36 and 42 which are integral with piers 1 and 4, respectively, as shown in Figure 4.

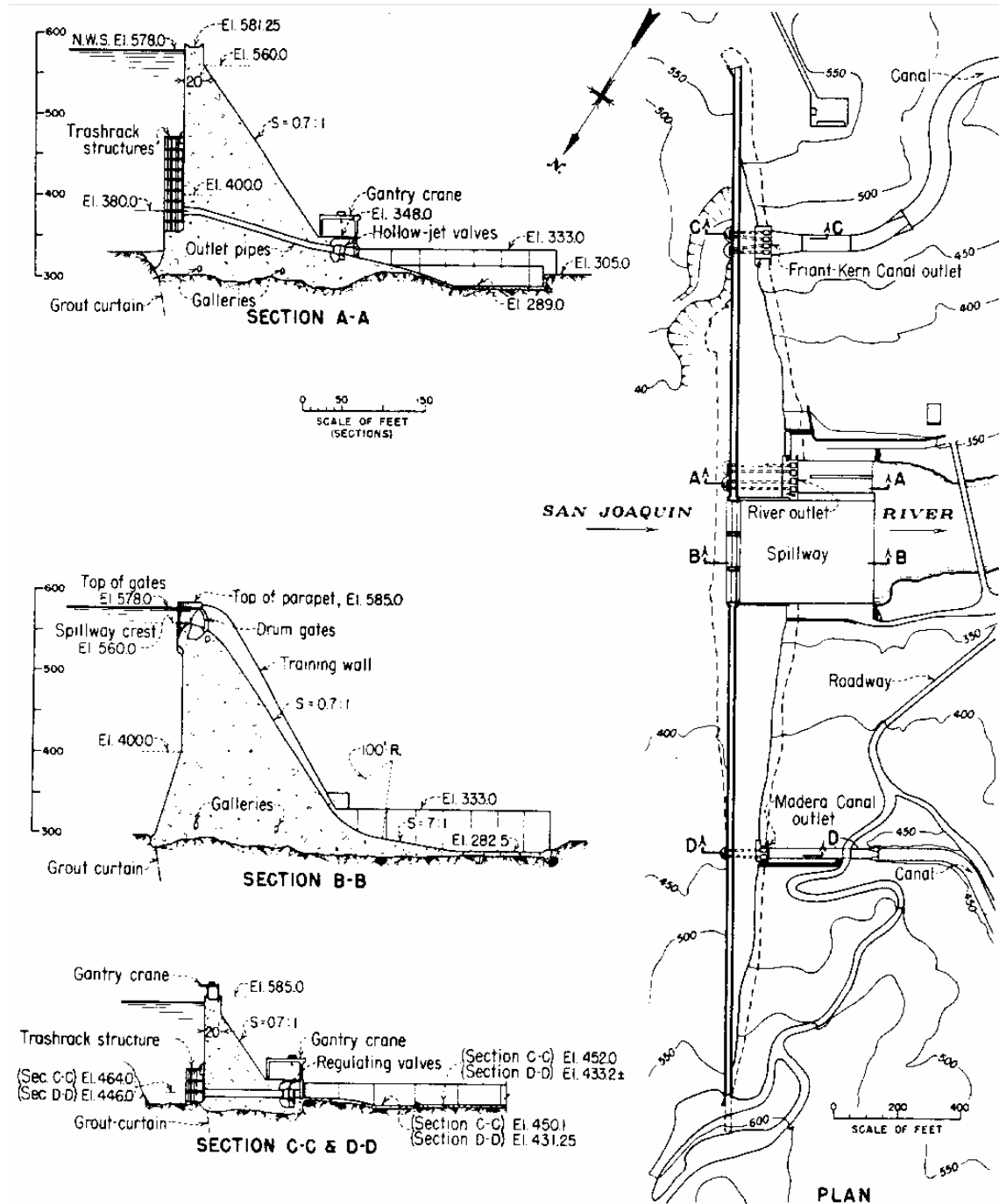


Figure 3. Friant Dam -- plan and layout.

It also appears that piers 2 and 3 are expanding due to alkali-aggregate reaction. A Review of Operations and Maintenance (RO&M) Category 1 recommendation was made to complete the study and modifications by fiscal year 1992. Consequently, a Planning Study was completed in March 1991 recommending either to rehabilitate the existing drum gates and replace the expanding and moving concrete, or to replace the existing drum gates with three 18 ft high by 100 ft wide rubber gates (dams). An Advanced Planning Study was completed in March 1992, recommending the drum gates be replaced with three rubber gates. Based on new information that the movement of the inside piers was not as significant as the outside piers, the Advanced

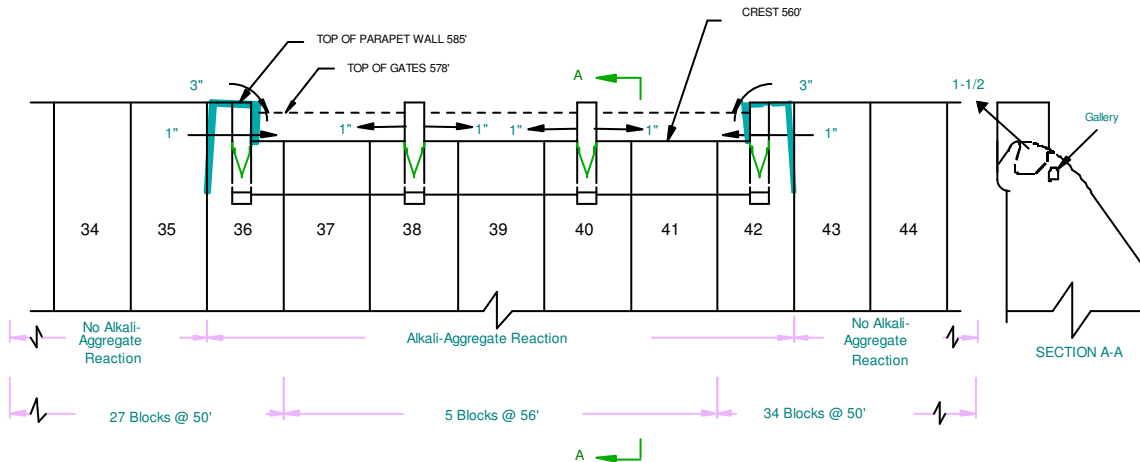


Figure 4. Friant Dam Spillway. The alkali-aggregate reaction in blocks 36 to 42 is causing the spillway bays to narrow. The existing left and right drum gates may become inoperable in 2 to 4 years.

Planning Study recommended consideration of replacing the outer drum gates with rubber gates, and rehabilitating the inside drum gate as shown in Figure 5. The Mid-Pacific (MP) Regional Office selected this option as the preferred alternative.

The Advanced Planning Study considered the risk of uncontrolled deflation due to puncture or tear alone to be extremely minimal. However, puncture or tears in conjunction with power or mechanical failure could prevent proper operation. Thus, redundant power and air supplies were recommended.

The 1993 Value Engineering Study, 1992 Advanced Planning Study, and the 1991 Planning Study concluded that rubber gates were the best alternative to accommodate the expanding concrete at Friant Dam Spillway. These studies considered several structural options. It was also concluded that the possibility of vandalism at site was minimal due to the lack of accessibility, thus special protective coatings to prevent cutting by knives are not needed. It was also concluded that the leakage from other punctures would be markedly less than the capacity of the air pumps.

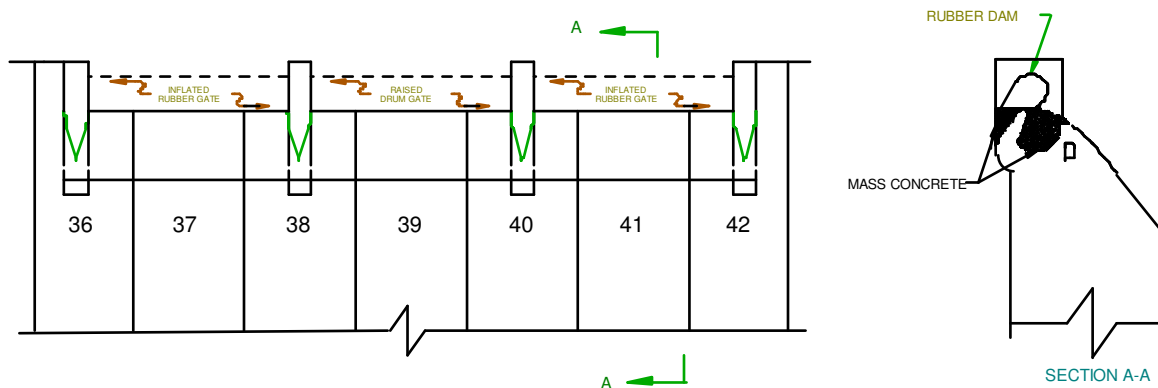


Figure 5. Preferred option for the spillway rehabilitation. Under this option, the two outside drum gates will be replaced with air-inflated rubber gates. The center drum gate will be rehabilitated.

PURPOSE OF STUDY

This scale model investigation provides information pertaining to the hydraulic performance of proposed modifications to the existing spillway of Friant Dam. Various configurations of the spillway were modeled, as well as various air-inflated rubber-gates to aid in the design. Other related purposes include:

- Optimize the approach structure for placement of the rubber gate and determine the head-discharge relationship of the modified structure at various reservoir water surface elevations.
- Test for and minimize effects of negative pressures on deflated rubber gates.
- Detect occurrence of rubber gate undulation and V-notch formation.
- Determine head-discharge relationship of rubber gates at different gate heights.
- Develop a gate positioning criteria with consideration of the stilling basin performance and hydraulic jump sweep out.

CONCLUSIONS

Of the three modified approach configurations tested for the ogee crest on the two outside bays, an elliptical approach was determined to have the best discharge characteristics and least impact on construction requirements. The elliptical approach also reduces the amount of construction materials and labor required.

The elliptical approach provides over 11 ft of flat surface for rubber gate placement. The length from the beginning of the flat surface to the point where negative pressures occur on the downstream spillway is 23 ft.

The standard 18 ft high Sumigate undulated under the design maximum (6 ft) overtopping because it was designed for 3.6 ft of overtopping.

The specially designed Sumigate performed well for hydraulic control for gate heights greater than 12 ft. Due to hysteresis, this gate cannot be used to measure the flow. The nearly deflated specially designed Sumigate undulated due to the end extending into the negative pressure zone.

The Bridgestone gate performed well as a hydraulic control and to determine flow for water surface elevations up to 584 ft and gate heights greater than 10 ft.

The stilling basin performance was adequate if the recommended gate positioning criterion is used.

HYDRAULIC MODELING PREPARATION

Model Construction

The Friant Dam Model consisted of a head box, tail box, and the spillway spanning between the two boxes (Figure 6).

A 10 ft long by 28 ft wide by 8 ft deep head box was used to model the reservoir, spillway bays, and dam parapet wall. It modeled 288 ft upstream of the upstream face of the dam, 1008 ft dam width, and 150 ft below the spillway crest. The dam parapet wall was modeled for 227 ft left of the spillway, and 125 ft right of the spillway. The center spillway bay included a moveable facsimile of a drum gate and existing approach structure. In the two outside spillway bays the approach was modified with two semi-circular and one elliptical section without rubber gates. The two

outside spillway bays were modeled with the elliptical section and with rubber gates installed. The river outlet works were included and throttled with an 8 inch butterfly valve in the model to simulate the outlet works discharge.

The 26 ft by 22 ft by 4 ft tail box was used to contain the model, the spillway, and river outlet works stilling basins and river topology. This region covered an area 936 ft wide, with 145 ft on the left of the river outlet works stilling basins and 156 ft on the right of the spillway stilling basin, and 489 ft downstream from the end of the stilling basins.

Operational Considerations

A new probable maximum flood (PMF) was approved for use in the Safety Evaluation of Existing Dams (SEED)

Program in the memorandum from the Manager, Planning Services, to the Regional Director, Sacramento, California, dated October 7, 1988. The PMF has a peak discharge of 574,000 ft³/s and a 15-day volume of 2,454,000 acre-feet.

A preliminary Emergency Spillway Release Diagram proposed by the Corps of Engineers in 1989 is still under review. The preliminary diagram proposes to change the maximum permissible induced surcharge from 584 ft to 581.25 ft. This model study used the routing based on the 1979 diagram that has a maximum permissible induced surcharge from 584 ft.

For this study, the Mid-Pacific Regional Office has requested that the inflow design flood (IDF) would peak just before overtopping the dam at elevation 585 ft. Technical Memorandum No. FRD-3110-1-90 states that by using the standard operating procedures for downstream releases, 28 percent of the PMF will result in a maximum reservoir surface (RWS) of 585 feet. Thus the IDF is equated to the 28 percent of the PMF.

Similitude

Froude law relationships were used in this study to ensure the fluid's dynamic similarity. The Froude number was chosen because the hydraulic performance of the model and prototype structures are primarily dependent on gravitational and inertial forces. The Froude number¹ is:

$$F = \frac{V}{\sqrt{Lg}}$$



Figure 6. The Friant Dam Model.

¹ *Hydraulic Laboratory Techniques*, p. 51, United States Government Printing Office, Denver, 1980.

where V is the velocity, L is the characteristic length, and g is the acceleration of gravity. Froude similitude is achieved by setting the model's Froude number, F_m , equal to the prototype's Froude, F_p , number, such that

$$\frac{F_m}{F_p} = \frac{V_m}{V_p} \sqrt{\frac{g_p L_p}{g_m L_m}} = 1$$

where, $_m$ refers to the model and $_p$ refers to the prototype. The 1:36 scale model of Friant Dam has the following scaling relations:

Length ratio:

$$L_r = L_m / L_p = 1 / 36$$

Velocity ratio:

$$V_r = L_r^{1/2} = (1/36)^{1/2} = 1 / 6.0$$

Discharge ratio

$$Q_r = L_r^{5/2} = (1/36)^{5/2} = 1 / 7,776$$

Time ratio:

$$T_r = L_r^{1/2} = (1/36)^{1/2} = 1 / 6.0$$

These ratios are applied by multiplying the prototype value by the appropriate ratio to obtain the model value. For example, the prototype discharge of 50,000 ft³/s is scaled to a 1:36 Froude scale model discharge by

$$\frac{50,000 \text{ ft}^3 / \text{s}}{7,776} = 6.43 \text{ ft}^3 / \text{s} .$$

The Structural Merit law relationships were used to approximate the rubber gate fabric's dynamic similarity for elongation. The Structural Merit number² was chosen because the performance of the model gate fabric and prototype gate fabric dynamic similarity for elongation is primarily dependent on gravitational and elasticity forces. The Structural Merit number³ is:

$$S = \frac{L\gamma}{E}$$

Where γ is the material's unit weight, and E is the modulus of elasticity and is;

$$E = \frac{\sigma}{\epsilon} = \frac{\frac{\text{force}}{\text{area}}}{\frac{\text{elongation}}{\text{length}}}$$

Structural Merit similitude is achieved by setting the model's Structural Merit number S_m equal to the prototype's Structural Merit S_p number, such that

² *The Land Chart of Dimensionless Numbers*, Omega Engineering, Inc., 1991.

³ Clifford A. Pugh, *Hydraulic Model Studies of Fuse Plug Embankments*, p. 6, Bureau of Reclamation Report No. REC-ERC-85-7, Denver, 1985.

$$\frac{S_m}{S_p} = \frac{L_m \gamma_m E_p}{L_p \gamma_p E_m} = 1$$

This gives,

$$\frac{g_p L_p}{E_p} = \frac{g_m L_m}{E_m}$$

By rearranging and applying the geometric length ratio,

$$\frac{\gamma_p E_m}{\gamma_m E_p} = \frac{L_m}{L_p} = L_r = \frac{1}{36}$$

Separating the equations,

$$\frac{\gamma_p E_m}{\gamma_m E_p} = \frac{1}{36}$$

$$\frac{L_m}{L_p} = \frac{t_m}{t_p} = \frac{1}{36}$$

where t_m is the model fabric thickness and t_p is the prototype fabric gate thickness.

Since a fabric with the exact thickness and elasticity required can not be found on the market and is very expensive to manufacture, it is necessary to evaluate off-the-shelf fabrics. This is done multiplying the last two equations such that an increase in the model fabric thickness will decrease the required model fabric elasticity appropriately.

$$\frac{\gamma_p E_m t_m}{\gamma_m E_p t_p} = \frac{1}{36^2}$$

$$\frac{36^2 \gamma_p E_m t_m}{\gamma_m E_p t_p} = 1$$

The bending stiffness number⁴ was chosen because the performance of the model gate fabric and prototype gate fabric dynamic similarity for bending is primarily dependent on inertial and elasticity forces. The bending stiffness number is EI where E is shown above and I (the moment of inertia) is:

$$I = \frac{bt^3}{12}$$

To evaluate the scale ratio of prototype to model bending stiffness, $E_p I_p = (L_r E_m)(L_r^X I_m)$, where X is an unknown, the maximum beam deflection equation is used:

$$\Delta = \frac{5wl^4}{384EI}$$

For geometrically scaled fabrics, $\Delta_p = L_r \Delta_m$, $E_p = L_r E_m$, $w_p = L_r w_m$

⁴ *The Land Chart of Dimensionless Numbers*, Omega Engineering, Inc., 1991.

$$\Delta_p = \frac{5w_p L_r^4}{384E_p I_p} = \frac{5(L_r w_p)(L_r L_m)^4}{384(L_r E_m)(L_r^X I_p)} = \frac{5w_m L_r^{4-X}}{384E_m I_m} = L_r \Delta_m$$

so $4-X=1$, $X=3$ and

$$E_p I_p = (L_r E_m)(L_r^3 I_m) = L_r^4 E_m I_m$$

$$\frac{36^4 E_m I_m}{E_p I_p} = 1$$

Tailwater Stage-Discharge Relationship

Tailwater elevations for this study were taken from a February 1, 1991, memorandum concerning a flood study at Friant Dam⁵. The actual values used in this study are shown in Figure 7.

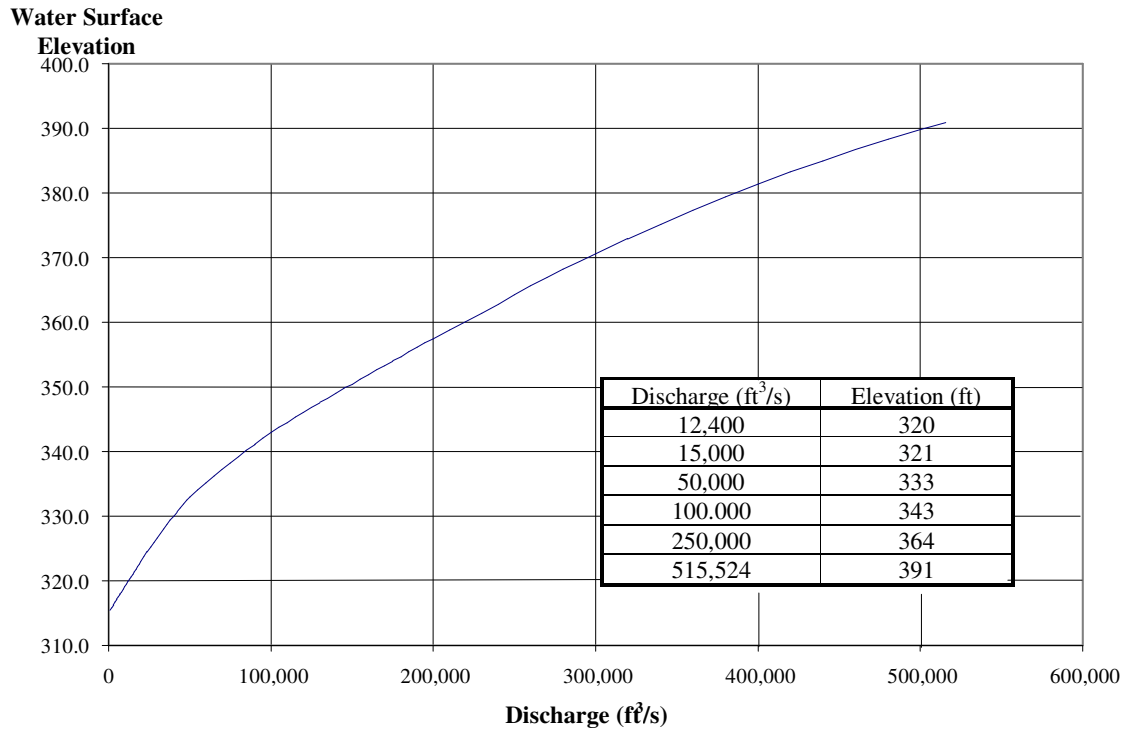


Figure 7. Tailwater rating curve for the San Joaquin river downstream of Friant Dam.

⁵ Memorandum, Tailwater Curve for Friant Dam up to Probable Maximum Flood - Central Valley Project, California, From Chief, Surface Water Branch to Chief, Concrete Dams Branch, Feb. 1, 1991.

INVESTIGATION

Optimum Crest Shape

The crest was modified to ease the installation, maintenance, and to improve operation of the rubber gates. The shape was optimized for discharge, and pressures were measured to determine where negative pressures will develop. The negative pressures may have a detrimental effect on the gate material if the layout length is too long.

Three crest configurations were tested. All three had a horizontal portion to construct the rubber gate. The three configurations tested were:

- a 7 ft 1-1/2 in bull nose (Figure 8)
- which extends upstream of the existing corbel, a 10 ft 6 in bull nose (Figure 9) which also extends upstream of the existing corbel, and
- an elliptical section (Figure 10).

Figure 11 displays the different stage-discharge relationships for the modeled configurations. The 10 ft 6 in bull nose displays a shift in control while the elliptical configuration produces the most discharge over the tested range.

Negative pressures were investigated to determine maximum layout length. Negative pressures at the end of a deflated or nearly deflated gate may cause the gate to undulate. Measured pressures are shown in figures 12 - 17.

The elliptical configuration was chosen because it has the best discharge characteristics. The elliptical section also reduces the amount of construction materials and labor required. The maximum rubber gate layout length for this configuration is 23 ft.

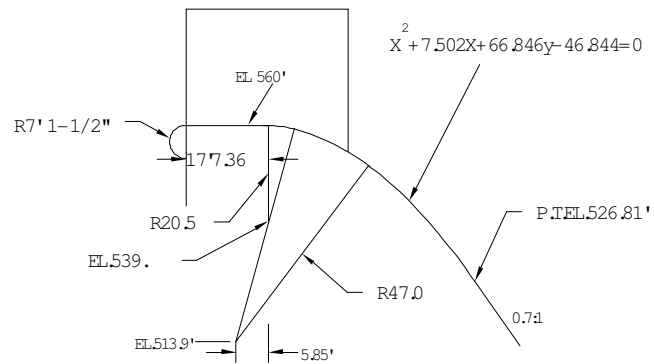


Figure 8. Details of the 7' 1-1/2" bull nose.

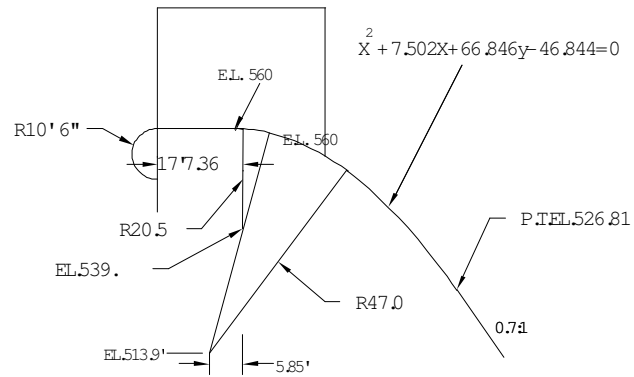


Figure 9. Details of the 10' 6" bull nose.

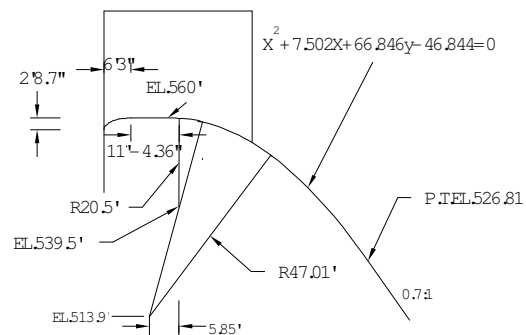


Figure 10. Details of the elliptical configuration.

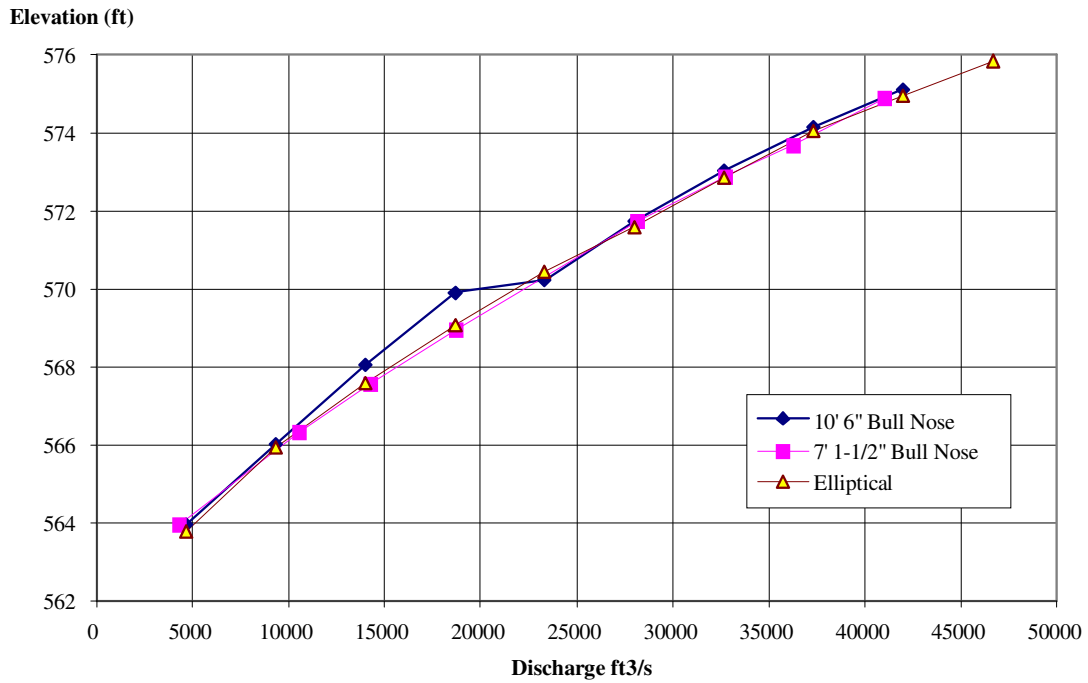


Figure 11. Stage-discharge for the modeled approach configurations.

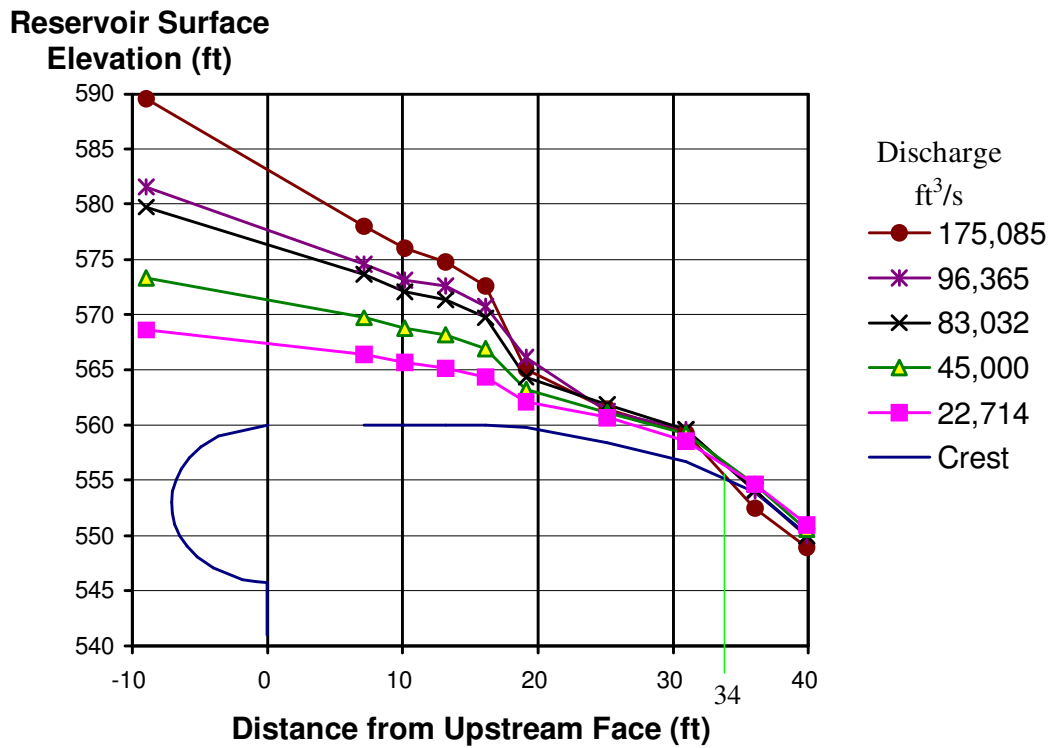


Figure 12. Pressures for the 7 ft 1-1/2 in configuration, measured at the left side of the spillway bay. The maximum rubber gate layout length for this section is 34 ft.

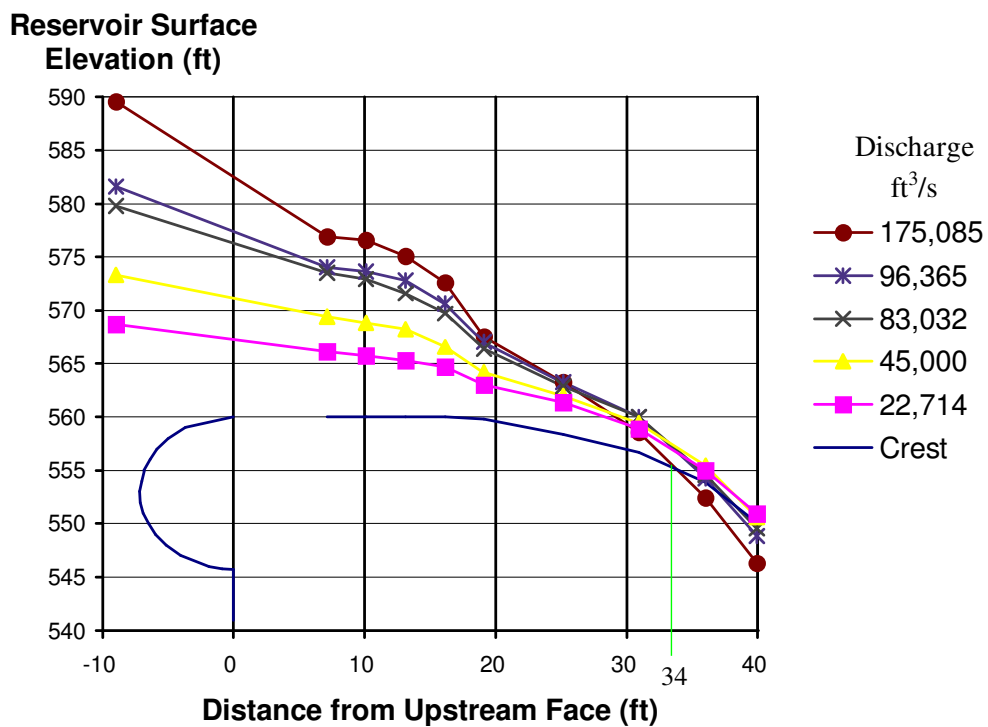


Figure 13. Pressures for the 7 ft 1-1/2 in configuration, measured at the center of the spillway bay. The maximum rubber gate layout length for this section is 34 ft.

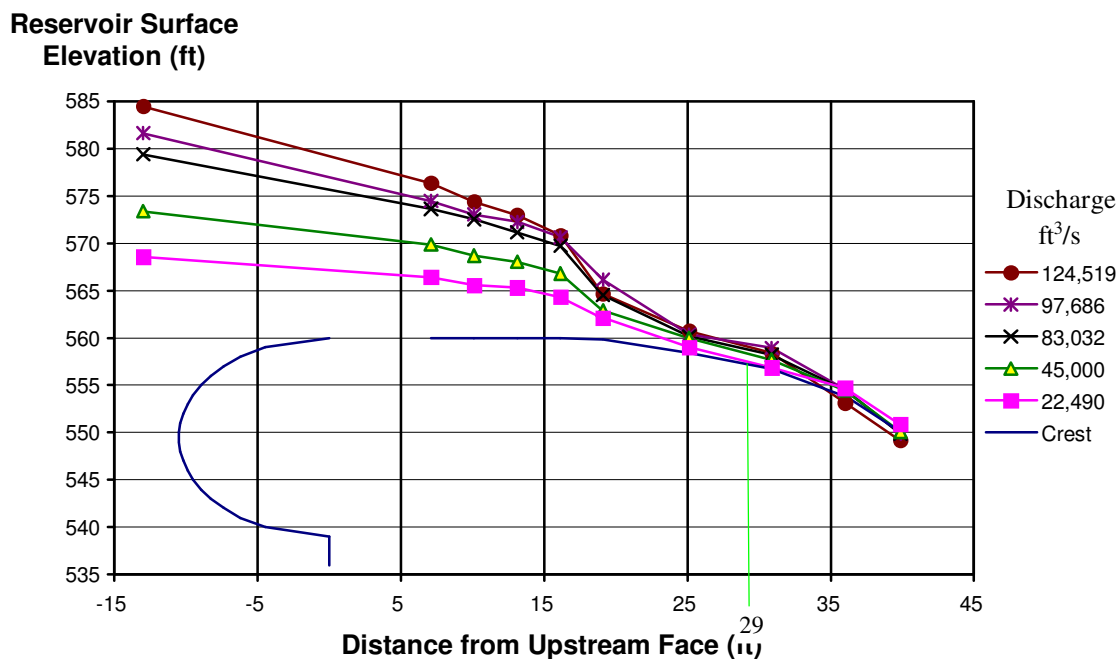


Figure 14. Pressures for the 10 ft 6 in configuration, measured at the left side of the spillway bay. The maximum rubber gate layout length for this section is 29 ft.

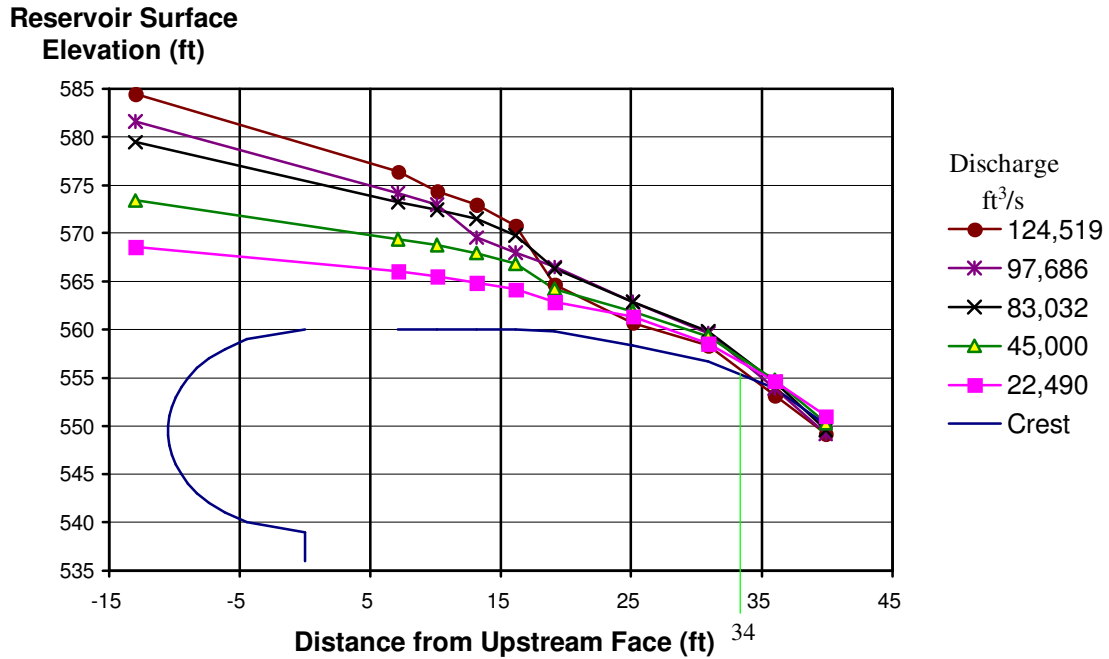


Figure 15. Pressures for the 10 ft 6 in configuration, measured at the center of the spillway bay. The maximum rubber gate layout length for this section is 34 ft.

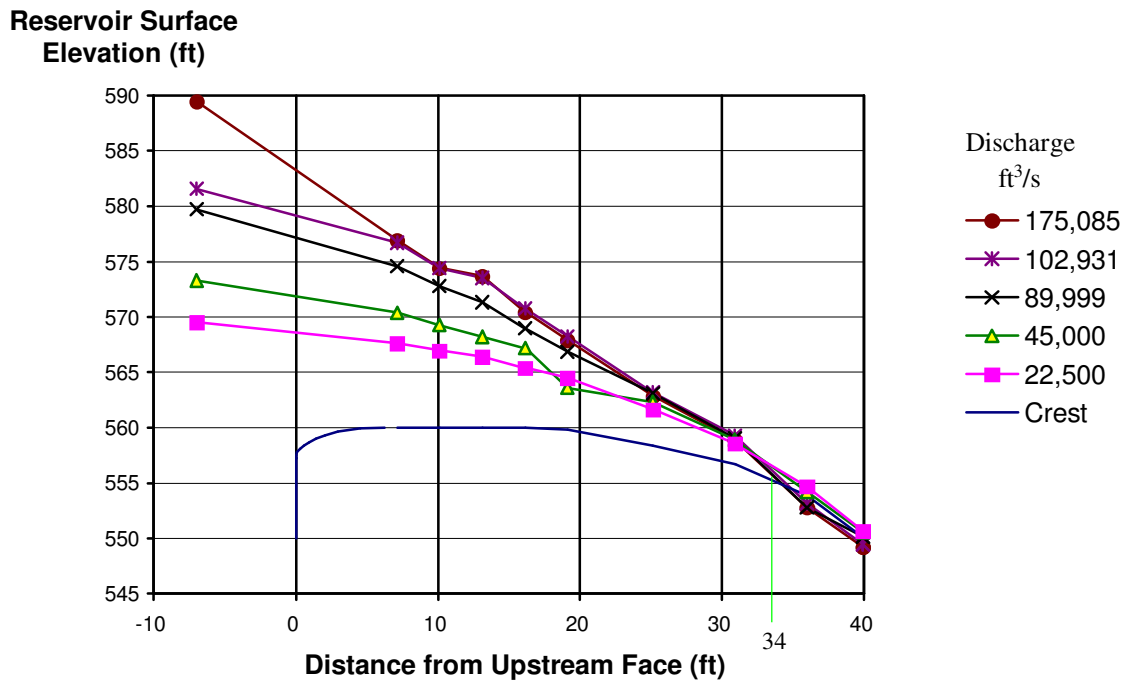


Figure 16. Pressures for the elliptical configuration, measured at the left side of the spillway bay. The maximum rubber gate layout length for this section is 28 ft.

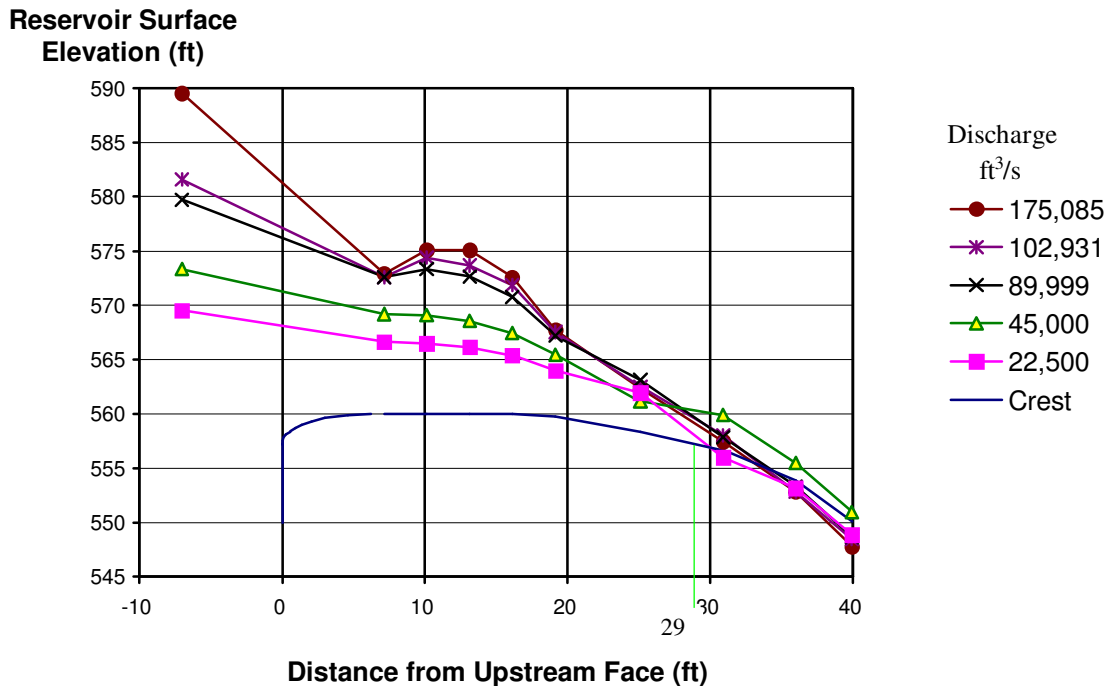


Figure 17. Pressures for the elliptical configuration, measured at the center of the spillway bay. The maximum rubber gate layout length for this section is 23 ft.

Rubber Gate Fabric Evaluation and Gate Construction

Structural Merit law relationships were used to simulate the rubber gate fabric's dynamic similarity for elongation, and the bending stiffness number was used to ensure the rubber gate fabric's dynamic similarity for bending.

The elongation and bending characteristics of rubber gates change with time and use. These changes are greatly dependent on the materials of the composite section. Despite this variation of characteristics, testing of geometrically similar gates with different elongation and bending characteristics has shown that a fabric with the general order of magnitude of the Structural Merit number and the bending stiffness number demonstrated similar characteristics. The physical properties of the manufacturer's fabric and model materials are shown in Table 1 and Table 2.

Table 3 displays a matrix that compares model fabric suitability to prototype fabric requirements. The fabric ratios that were selected are shown in bold. Values less than 1 indicate the fabric is less stiffness than required, values greater than 1 has more stiffness than required.

Sumigate rubber gate model #1

The first Sumigate model used a standard 18 ft Sumigate design. A standard Sumigate allows for 20 percent overtopping, in this case, 3.6 ft of overtopping. The actual design overtopping head was 6 ft. Also, due to miscommunications, this model used gum rubber as the model fabric, which has an elongation number that is too low (Table 3).

Fabric	Sample thickness (in)	Stress at 5% elongation (psi)	E at 5% elongation (psi)	Specific weight (lbs/in ³)
Sumigate	0.585	4,000	80,000	0.043
Bridgestone	0.92	1,580	31,600	0.045
Sumitomo coated fabric #1	0.0115	491	9820	0.044
Sumitomo coated fabric #2	0.0255	429	8580	0.044
Neoprene rubber	0.0310	86.3	1727	0.052
Gum rubber	0.0385	190.1	381.6	0.036

Table 1. Modulus of elasticity at 5 percent elongation and specific gravity.

Fabric	Sample thickness (in)	E (psi)	I (in ⁴)	EI (lbf-in ²)
Sumigate prototype	0.65	1,100	0.023	25
Bridgestone prototype	0.92	3,300	0.065	210
Sumitomo coated fabric #1	0.0112	8,200	1.17 E-7	9.5 E-4
Sumitomo coated fabric #2	0.0258	2,900	1.43 E-6	4.2 E-3
Neoprene rubber	0.0315	1,200	2.60 E-6	3.0 E-3
Gum rubber	0.0375	220	4.39 E-6	9.7 E-4

Table 2. Fabric resistance to bending.

	Sumigate		Bridgestone	
	Elongation $\frac{36^2 \gamma E_m F_m}{\gamma E_p F_p} = 1$	Bending $\frac{36^4 E_m I_m}{E_p I_p} = 1$	Elongation $\frac{36^2 \gamma E_m F_m}{\gamma E_p F_p} = 1$	Bending $\frac{36^4 E_m I_m}{E_p I_p} = 1$
Sumitomo coated fabric #1	5.23	63.8	8.81	7.59
Sumitomo coated fabric #2	9.14	282.	15.4	33.5
Neoprene rubber	1.22	201.	2.06	23.9
Gum rubber	0.486	65.1	0.819	7.75

Table 3 Model fabric selection matrix. The fabric ratios that were selected are bold. Values less than 1 indicate the fabric is less stiff than indicated by scaling laws, values greater than 1 have more stiffness than indicated. All of the fabrics evaluated were much stiffer than necessary to simulate bending. Sumitomo coated fabric #1 was the closest to the properties needed, 63.8 times too stiff, but only slightly more flexure in the prototype is expected.

Sumigate model #2

As can be seen from Table 3, the Sumitomo coated fabric #1 was the best match for bending stress, while the neoprene rubber matched best for elongation. Both of these materials were tested and compared with Sumitomo coated fabric #2. Sumitomo provided a gate using coated fabric #2, for this study.

This gate required special design due to high overtopping requirements. The construction details are shown in Attachment #1, and have a much wider anchor spacing and layout length when compared to the first Sumigate design.

All three fabrics performed essentially the same, so further testing was performed with Sumitomo coated fabric #2.

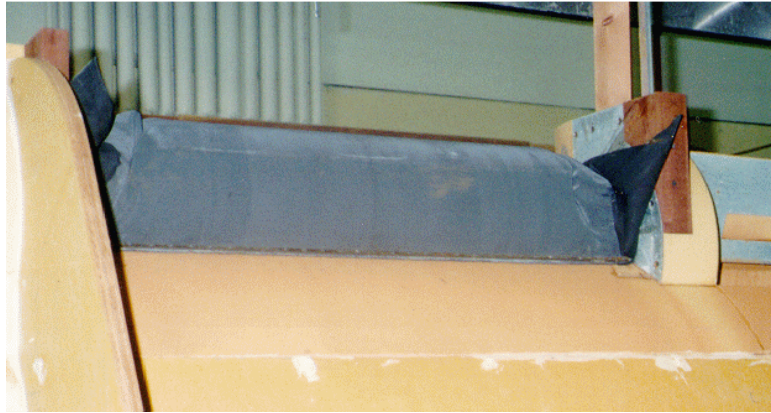


Figure 18. Sumigate model #2. The pier extensions were added after this photograph was taken.

Bridgestone model

As can be seen from Table 3, the neoprene fabric matched best for elongation, and was the only fabric used to model the Bridgestone gate.

This gate required special design due to its high overtopping requirements and is shown in Attachment #2.

Rubber Gate Performance

Performance: The main criterion for performance of rubber gates used in this study was the ability to control flow up to water surface elevation 584 ft. Undulations were not allowed for any gate height for water surface elevations between 560 ft and 584 ft.



Figure 19. Bridgestone model.

Flow Determination: To determine flow for flood routing, the average weir height of the gate needs to be measured. For these tests, it was assumed that a line of site from the base of the

gate to the top of the gate would be required. Deflation of the upstream part of the gate or a large v-notch could obstruct the line of sight. Also, an asymmetrical gate shape would interfere with measurement of the average weir height, and was not included in the stage-discharge curves.

Sumigate rubber gate model #1

A standard 18 ft high Sumigate design allows for 20 percent overtopping (3.6 ft). The design flood includes up to 6 ft of overtopping. This gate undulates under the higher head conditions. According to a Sumitomo technical guide⁶, this gate clearly would undulate under the higher overtopping heads. The higher overtopping conditions constitute an improper application for the standard 18 ft Sumigate. There was no further testing of this model gate.

Sumigate model #2

Performance: This gate performed well under most conditions. High flow and nearly deflated gate conditions experienced undulations. Study of the layout length and the pressures in Figure 16 and Figure 17 shows that the end of the gate is in a negative pressure zone. An even more severe negative pressure is created by the bulge at the end of the gate due to remaining air when it is almost deflated.

This causes the gate to lift in an unstable fashion that causes oscillations. Testing this gate with fillets and without fillets had little impact on the nature of the oscillations. These oscillations may be avoided by reducing the layout length and moving the gate further upstream.

Flow Determination: This gate had a reasonable crest shape and gate shape for heights greater than 12 ft. However, this gate demonstrated hysteresis that depended on whether the gate was being inflated, or deflated. Moreover, the reservoir water surface elevation during the change of gate height contributed to the hysteresis. This produced highly variable discharge coefficients as shown in Figure 21.

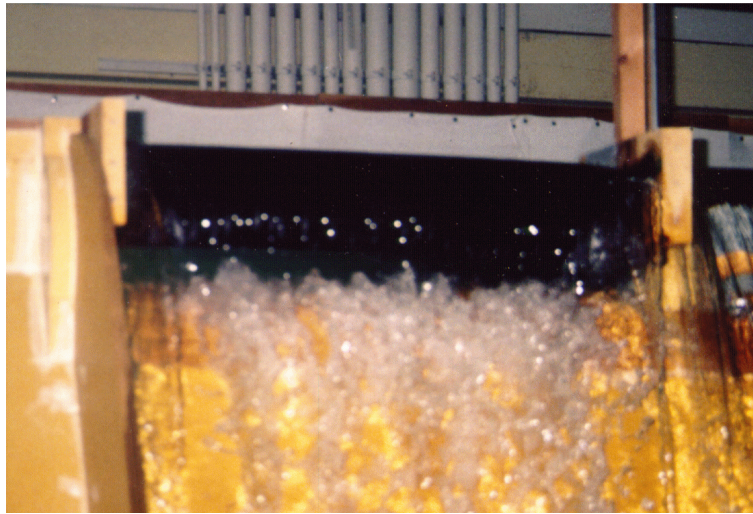


Figure 20. Sumigate model gate #2. This gate performed well with gate heights greater than 12 ft and all overtopping heads. When the gate was nearly deflated, it oscillated due to the end of the gate extending into the negative pressure zone.

⁶ Technical Description of Sumigate Inflatable Rubber Dams, Sumitomo Electric Industrial, Ltd., Oct. 1985.

Bridgestone model

Performance: The Bridgestone gate performed well under all heads and all gate positions. This gate displayed excellent hydraulic characteristics. It had an aerated nappe for all discharges and gate heights.

**Reservoir Water
Surface Elevation**

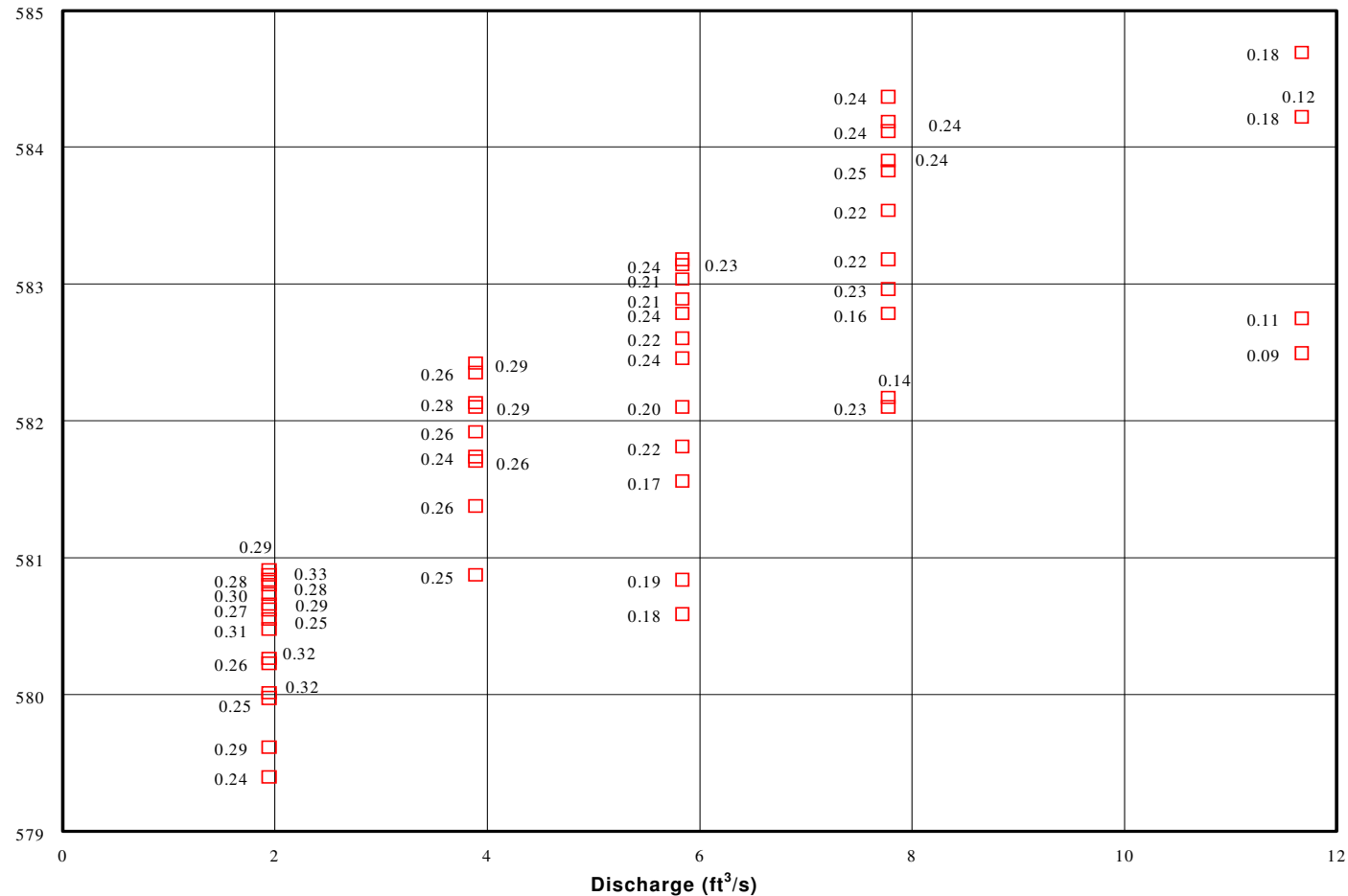


Figure 21. Sumigate model #2 stage-discharge coefficients for various gate heights. This gate demonstrated hysteresis that depended on whether the gate was being inflated, deflated, and the reservoir water surface elevation during the change of gate height. Highly variable discharge coefficients resulted as shown above.

Flow Determination: This gate can be used to determine flow for water surface elevations up to 584 ft and for gate heights greater and equal to 10 ft. Figure 23 shows the stage-discharge curve for various gate heights. Below 10 ft, this gate demonstrated hysteresis, indicated by not having consistent discharge coefficients.

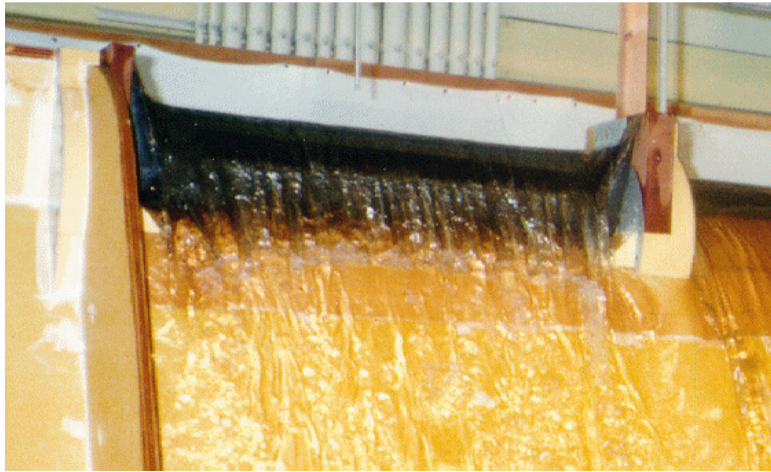


Figure 22. Bridgestone model gate. The notched fin maintained an aerated nappe for all discharges and all gate heights.

Gate Positioning Criteria

To deliver a specific discharge while using rubber gates as a flow control device while providing good stilling basin action, a gate positioning criteria is recommended. Results from Figure 23 were added to results from a 1945 model study⁷ (Figure 24) to determine the criteria. The

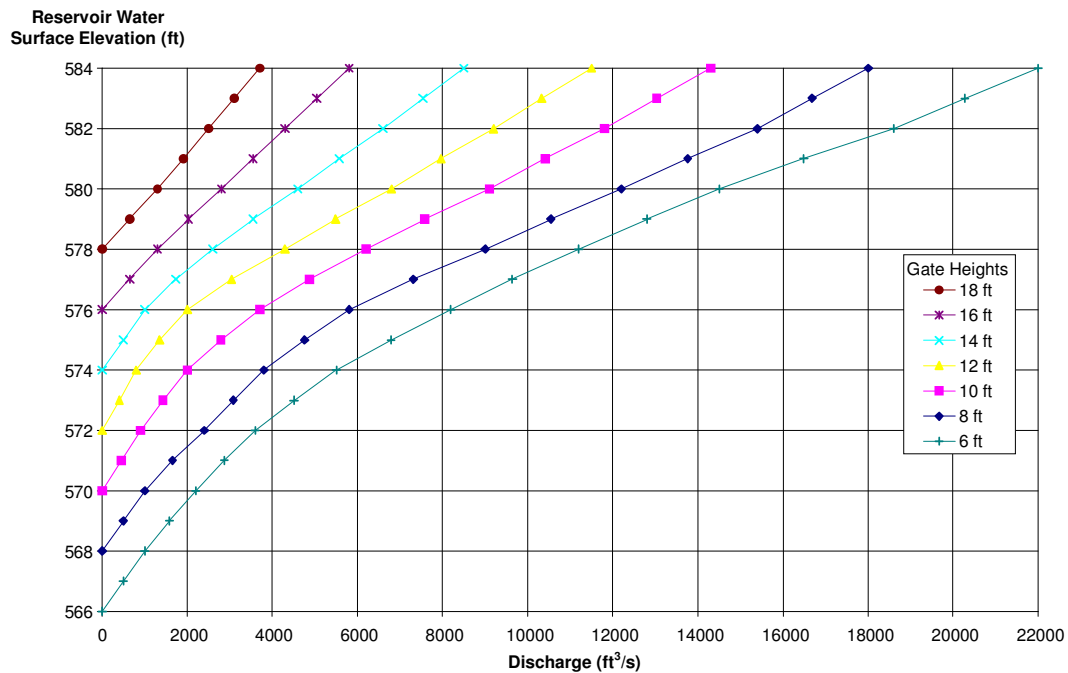


Figure 23. Stage-discharge curve for the Bridgestone gate. While this chart shows curves for gate heights of 6 ft and 8 ft, the weir heights are not readily measurable for all discharges at these gate heights.

recommended gate positioning criteria for using Bridgestone gates is illustrated in Figure 25. The stilling basin performed adequately for the extreme discharge conditions in the recommended criterion.

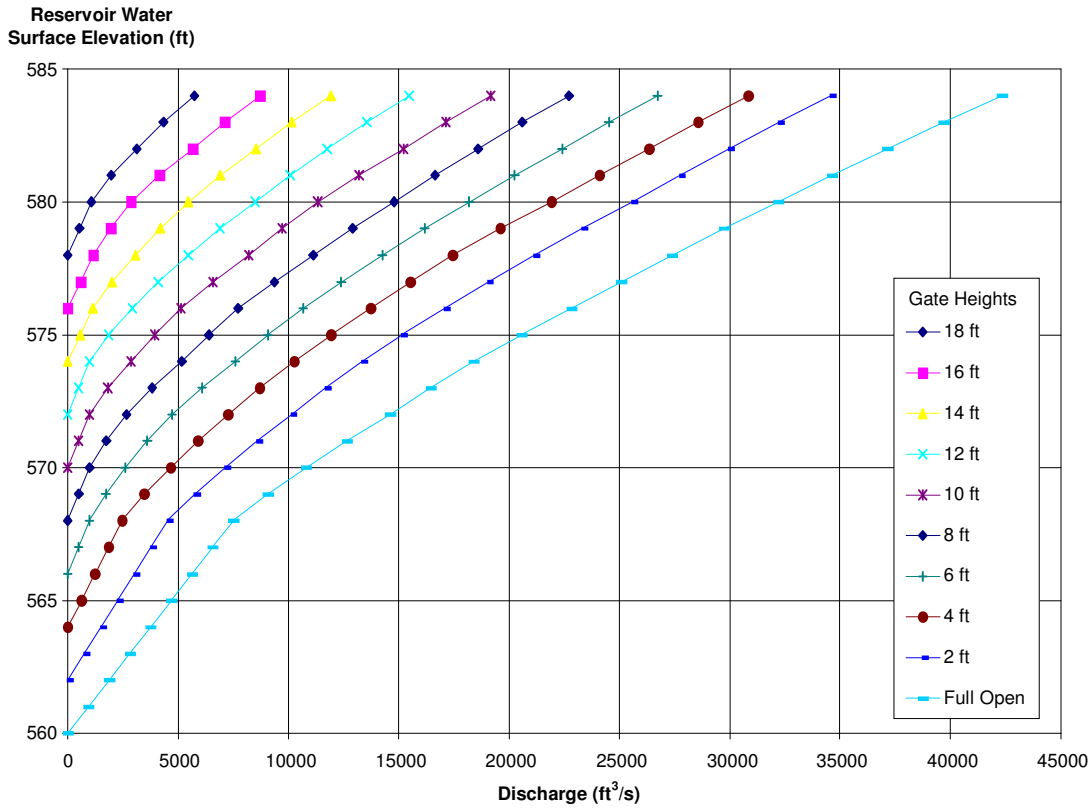


Figure 24. Single bay discharge using specific drum gate heights. This data was interpolated from the 1945 model study.

RECOMMENDATIONS

Due to possible changes in construction details such as anchor placement and pier modifications, a field verification study is recommended to confirm the stage-discharge relationships used in this report.

⁷ Model Studies of the Friant-Kern Canal Outlets; Friant-Madera Canal outlets; and the Friant Spillway and River Outlets, Friant Dam, Central Valley Project-California, Hydraulic Laboratory Report No. Hyd. 166, Feb. 23, 1945

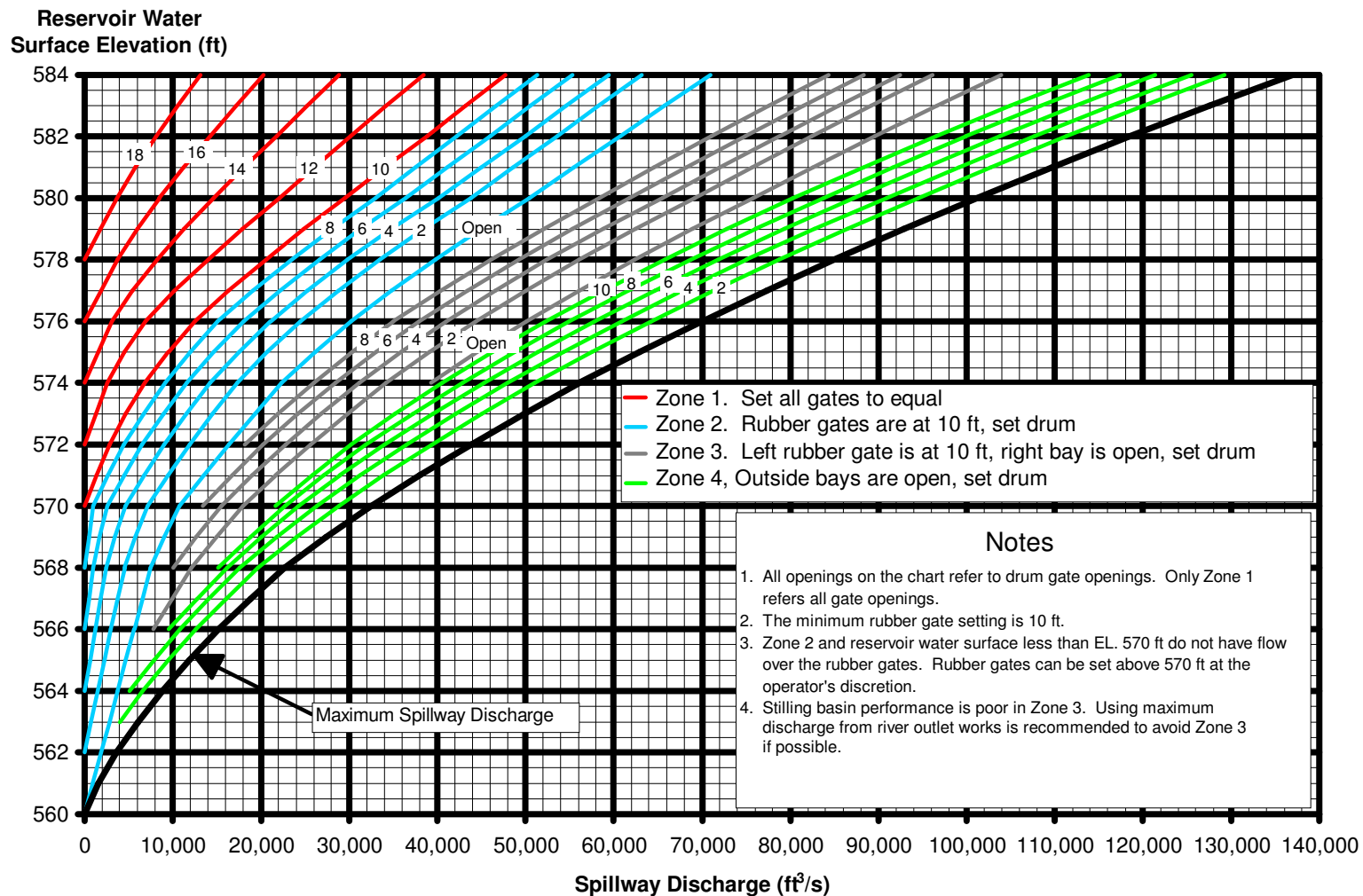


Figure 25. Recommended spillway gate positioning criteria for using Bridgestone gates in the outside bays.

1,6,11-14,16,19-21

+7

8,13,18-21,23,24,26-28

p1s6, p6s6, p11s6-p14s6, p16s6, p17s6, p19s8-p21s9